CHAPTER 9
QUALITY CONTROL OF GEOPHYSICAL SYSTEMS AND RELATED OPERATIONS

9-1. Introduction.

a. The general objective of geophysical investigations during a munitions response is to efficiently locate buried MEC so it can be properly evaluated, recovered and disposed. Specific geophysical investigation objectives of a project are defined by the PDT and will be measurable and attainable. They may also be risk-based, meaning finding MEC during QC or QA inspections that are deeper and more difficult to reliably detect may not always constitute a major defect.

b. In this chapter we discuss quality in the context of the *geophysical system* as defined in the introduction to Chapter 8. Since MEC geophysical systems make use of both digital geophysical mapping (DGM) and/or analog geophysical mapping (also referred to as "mag and flag" or "mag and dig" operations), this chapter will often highlight whether a particular topic is relevant to DGM systems, analog systems, or both. When a topic is specific to systems using digital techniques, we either put the word "digital" or the term "DGM" in parentheses after the topic, for systems using analog tools, we put the word "analog" in parentheses. Topics relevant to both types of systems will have the words "analog and digital" in parentheses. The reader is referred to Chapter 8 of this document for more details on digital and analog geophysical systems.

c. On munitions response projects, there are two elements subject to Geophysical QC/QA: processes and products. "Processes" are the project-specific geophysical planning and data collection/data analysis procedures and all related field activities performed. "Products" are the final project-specific deliverables and results that are achieved. The products must be defined by the PDT and will vary depending on the type of project being performed. For example, the remedial action product of having a cleared parcel of land is more important than it is for a characterization project, which may only require a parcel be characterized as having MEC contamination or not. Other possible deliverable products include properly formatted raw and processed geophysical data, legible geophysical maps, complete interpretations, complete dig sheets with all relevant geophysical data and intrusive results, complete project reports, and complete quality control documentation in accordance with the quality control plan.

d. Both the project processes and the project products will be part of a formal quality management process in order to demonstrate that project objectives are met. In most instances where geophysical systems are used, whether digital or analog, emphasis will be placed upon process quality management because the success, or failure, of geophysical products is highly dependent upon how the systems are used. The intent of this chapter is to provide a guide for the PDT in identifying the important aspects of geophysical systems that will require monitoring for quality. When formulating a quality control plan or quality assurance activities, this chapter provides options that can be selected and tailored to the specific geophysical system(s) that will be used by the PDT. Details on how to plan and manage specific quality assurance activities are provided in the Quality Assurance Surveillance Plans Chapter. The QC plans and QC tests that are designed as a function of the guidance in this chapter will often be reflected as elements of a project's quality assurance surveillance plan.

9-2. Process Quality Management.

a. Quality control of the processes used to perform geophysical operations should focus on demonstrating "good data" and "good results" are produced. The PDT should explicitly define what "good data" means. Statements such as "a clean site" or "a well characterized site" are ambiguous and can not be used to develop rigorous quality control or quality assurance programs. Typically, the term "good data" is used to identify specific work products or specific definable features of work that are the result of specific work tasks or work functions. These tasks and functions can be viewed as "key procedures" in QC programs, and the individual components of the geophysical systems used in performing those procedures are referred to as sub-systems. Breaking the work processes into key procedures and key sub-systems helps the PDT identify "how the work will be done" as well as "which tools will be used". Doing so helps the PDT develop QC functions for each and helps focus attention to those procedures or tools that may be prone to failure or degradation in the quality of their product(s). The following are key procedures requiring special attention when developing QC programs:

(1) Site preparation procedures

(2) Data acquisition procedures

(3) Data processing procedures,

(4) Anomaly selection processes,

(5) Anomaly reacquisition and marking procedures

(6) Anomaly excavation and resolution procedures

b. Critical sub-systems requiring specific monitoring and/or testing in QC programs include:

(1) The geophysical instruments

(2) The operators

(3) Positioning systems

(4) Geodetic surveys

c. Once these critical components and their failure modes have been identified, the PDT technical personnel will develop QC methods and measures (or tests) to ensure or demonstrate that the processes, as used by the contractor, achieve project objectives and produce good data. The QC tests and their related failure criteria must be specifically designed to test one or more key procedures or sub-systems. Rarely will a single QC test provide a thorough check of all possible failure modes for a given geophysical system. In many instances two or more QC methods will be used to monitor critical procedures and sub-systems. The PDT should verify all QC measures have been implemented and all QC tests meet their pass/fail criteria. Any test that fails should be fully addressed through root-cause analyses and corrective actions, before being accepted by the Government.

d. Listed below are elements of critical procedures and sub-systems that can be used to define what is meant by “good data”. These elements, if applicable, would be critical to the quality of all geophysical surveys performed to detect MEC. The frequency any one QC test should be performed to monitor these procedures should be determined by the PDT. Typical frequencies to be considered include: beginning of project, daily, start and end of day, start and end of collecting a dataset, per parcel of land basis, per operator basis (for analog systems), and/or per team basis (for analog systems, reacquisition and resolution operations).

(1) **Define Geophysical Systems Function Checks:** Purpose is to verify the geophysical system has not malfunctioned. Checked by performing repeatability tests, standard response tests, evaluating background noise levels, evaluating positioning accuracies and precisions, and re-sweeping or digitally mapping sections of analog geophysics lanes.

(2) **Define Survey Coverage Requirements:** Purpose is to clearly define overall survey coverage needs for all possible terrain/vegetation/obstruction conditions on-site. This topic must also address allowable gaps between adjacent DGM survey lines. Methods of checking coverage include reviewing track plots (non line-and-fiducial methods), calculating sizes of data gaps, implementing a blind seeding program using small metallic objects, and visual observations of line-and-fiducial, odometer and analog surveys.

(3) **Define Along-Track Measurement Interval Requirements:** Purpose is to clearly define along-track data density needs. Methods of checking along-track data density include calculating along-track sampling intervals (digital), calculating instantaneous point-to-point velocities (digital), visual observations (analog), and logging time-in-lane (analog).

(4) **Define MEC Detection and Anomaly Selection Criteria:** Purpose is to verify that anomaly selection criteria meet project needs. Criteria are normally defined during project planning and/or the GPO. Tested by reviewing documentation of anomaly selection criteria used for each dataset interpreted (digital), blind seeding for MEC detection and anomaly selection using inert or simulated MEC at or near maximum required burial depths (digital and analog), blind seeding using metallic objects that produce analog detection responses similar to,

or identical to MEC, digitally mapping sections of analog geophysics lanes to prove no MEC-like anomalies remain, re-sweeping analog geophysics lanes using analog tools to prove no MEC-like anomalies remain.

(5) **Define Anomaly Reacquisition Requirements**: Purpose is to verify detected and selected anomalies are marked for excavation. Checked by setting Pass/Fail anomaly repeatability criteria, setting Pass/Fail maximum allowable offset distances, testing efficacy of procedures for marking all localized anomalies during project planning and/or the GPO, and testing implementation of the false positives and no-contacts management plan during project planning and/or the GPO.

(6) **Define Anomaly Resolution Requirements:** Purpose is to verify the excavated item(s) adequately explain anomaly characteristics. This topic must also include criteria for accepting dig results reported as false positives, no-contacts, “geology” or “hot rocks”. Methods for testing anomaly resolution procedures include defining size/depth/weight criteria for various categories of anomaly characteristics, post excavation verifications using appropriate geophysical systems, and inspection of dig results and anomaly maps.

(7) **Define Process Specific Requirements for specialized or unique processes or sub-systems:** Purpose is to verify that procedures specific to a particular system are performed to meet project needs. Examples include: defining not-to-exceed survey speeds for systems sensitive to survey velocity, defining specific setup procedures for specialized positioning systems, and defining specialized function check requirements for systems requiring specialized function-checks or calibration.

e. Known Failure Modes of Common Geophysical Procedures. Tabulated below are possible failure modes for several key procedures and key sub-systems that are commonly used. The table also includes suggested quality control measures that can be implemented to monitor for possible failures.

Table 9-1: Common procedures and their related failure modes

Procedure	Failure Mode or Cause	Valid QC Checks
Geophysical Mapping, General	Contractor using un-authorized and/or un-tested equipment and/or unauthorized field procedures	1. Visual observations, 2. Verify the QC Plan is specific to the geophysical system(s) accepted/authorized for the project.
Instrument set-up	Broken equipment or bad cable connections	1. Static background test, 2. Static spike, 3. Cable shake tests, 4. Other system-specific function tests 5. Personnel Tests
Geophysical Mapping, General	Mapping coverage is not achieving required coverage goals	1. For analog methods and line and fiducial methods, visual observations 2. For digital methods, plot track-plots and review for coverage 3. For digital methods, use automated tools to calculate actual coverage achieved.
Line and Fiducial DGM, odometer trigger mode or time-based trigger mode	Insufficient or excessive measurements accrued along a segment	1. Check count of measurements at each end-of-line, 2. Check distance between along-line readings during post processing.

Procedure	Failure Mode or Cause	Valid QC Checks
		3. Collect repeat data
Line and Fiducial DGM, odometer trigger mode	Data gaps mis-positioned (e.g. gaps due to trees or other common obstructions) due to poor procedure or incorrectly entered values during acquisition or post-processing.	1. Measure actual location of gaps in the field and compare to those shown during processing. 2. Check track-plot maps for inconsistent along-line measurement spacing on both sides of gaps. 3. Collect repeat data
Line and Fiducial DGM, time-based trigger mode	Fiducial marks and/or start or end locations were mis-placed during acquisition or incorrectly entered during post-processing.	1. Create a map showing survey speeds or track-plots to check for line segments with inconsistent velocities or inconsistent measurement spacing 2. Collect repeat data
Line and Fiducial DGM, odometer and time-based trigger mode	Operator deviates laterally from the planned path	1. Visual observation during acquisition. 2. Placement of blind positioning seeds and confirming seeds are not detected on lines too far (laterally) from where they were placed. 3. Collect repeat data
Line and Fiducial DGM, odometer and time-based trigger modes	Data mis-positioned due to unsquare grid setup and/or grid dimensions are not as reported	1. Measure diagonals across grid to confirm 90 degree grid corners. 2. Measure lengths of grid boundaries

Procedure	Failure Mode or Cause	Valid QC Checks
DGM field procedures using automated positioning system	Data mis-positioned due to spikes or "erratic behavior" in the positioning solutions.	1. Create a map showing survey speeds and check for areas with inconsistent velocities. 2. If available, check positioning solution quality, such as HDOP, number of reference stations or satellites used, signal strength. 3. Collect repeat data
DGM field procedures using automated positioning systems	Data mis-positioned due to incorrectly entered sensor-to-positioning antenna offsets or incorrectly entered positioning system reference coordinates.	1. Place blind seeds throughout survey area and check they are detected within expected accuracies. 2. Perform the "clover-leaf" test over a known point(s) and verify the trackplots cross at proper coordinates.
DGM field procedures using automated positioning systems	Data mis-positioned due to incorrect base station coordinates or base station set-up over wrong location	1. Perform and record daily static positioning checks over known control points.
Digital Geophysical Mapping, Data Processing	Processing yields anomalies with atypical shape characteristics	1. Visual reviews of DGM maps for anomaly shape characteristics, 2. check interpreted locations of QC and/or QA seed items, 3. verify sensor to positioning antenna offsets,

Procedure	Failure Mode or Cause	Valid QC Checks
		4. check latency values used and check for changes in survey speed if simple "lag" corrections are used. 5. Perform latency tests
Digital Geophysical Mapping, Anomaly selections	Processing and anomaly selection methods produce excessive anomaly selections and/or anomalies are the result of gridding artifacts.	1. Visual review and/or automated verification of anomaly proximities, 2. overlay track-plots on gridded data to confirm all anomalies are real, 3. check drift corrections or filtering results in high gradient areas.
Anomaly Reacquisition, General	Low amplitude and/or small area anomalies reacquired beyond their footprint shown on DGM maps.	1. Define critical search radius (maximum not-to-exceed search radius) to encompass all possible anomaly size scenarios, or 2. provide anomaly-specific critical search radius (R_{crit}) based on anomaly footprint size.
Anomaly Reacquisition, General	Large and/or high amplitude anomalies reported as No-Contact or False-Positive.	1. Define threshold values above which additional reviews and/or field actions are required before being accepted. 2. If the reacquisition procedure does not use the exact same instrument model used to detect and

Procedure	Failure Mode or Cause	Valid QC Checks
		interpret anomalies, return to the location with the same model instrument.
Anomaly Reacquisition, process uses a system with inferior detection capabilities compared to those of the original mapping survey	Wrong anomaly is reacquired	1. Define limits for acceptable location offsets between interpreted location and flagged location, based on systems and processes used. 2. Compare dig results for each anomaly with the associated geophysical anomaly characteristics 3. After excavations, return with original detection system, to original interpreted location, for a portion or all anomalies and confirm no anomalies remain.
Analog geophysics (mag & flag operations)	Geophysical anomaly remains after mapping and digging operations are complete, anomaly source is unknown.	1. Re-map a portion or all of the area with a digital geophysical system and/or an analog system, 2. Place blind seed items at depths required to be cleared, place blind seed items at locations that are difficult to access.
Analog geophysics (mag & flag operations)	Large piece(s) of metal having MEC-like physical characteristics or that could be masking nearby MEC remains after mapping and digging operations are complete.	1. Re-map a portion or all of the area and excavate anomalies to confirm they do not meet failure criteria or to confirm all large pieces of surface metal have no MEC buried beneath them, 2. Place blind seed items throughout project area.
Analog geophysics (mag & flag operations)	Operator not achieving proper coverage, not using good sweep techniques, or not properly	1. Visual observations,

Procedure	Failure Mode or Cause	Valid QC Checks
	interpreting instrument measurements	2. re-sweeping by second party for presence of MEC-like anomalies, 3. Blind seeding to produce MEC-like signals similar to the MEC of concern.
QC Tests	Insufficient documentation or documentation not provided to COE within required deliverable schedule.	1. Verify PWS/SOW and contract states that QC documentation will be submitted to COE and the deliverable schedule, 2. Ensure COE has input into required QC documentation. 3. Ensure COE is notified of all root-cause analyses and that COE has authority to reject incomplete root-cause analyses and/or incomplete corrective actions.
Documenting excavation activities and dig results	Incomplete and/or inaccurate information recorded	1. Visual observations 2. Review information on recovered seed items 3. Check for consistent nomenclature in reported information

f. Example quality standards for geophysical procedures and how they are used. Some typical quality Pass/Fail tests for geophysical operations are listed below. Each is identified as applicable to digital mapping, analog mapping, or both. Normally, Pass/Fail criteria will be quantified or defined for each test performed. A brief description of how each test is implemented is also provided. When a specific test is used, it will normally be tailored to site-specific and contract-specific needs and requirements. Where applicable, Pass/Fail criteria should be defined based upon the current knowledge of the project site(s). The Pass/Fail criteria would normally be revised in the event new information about a site is discovered over the course of the project. If the examples below are used by the PDT, the example Pass/Fail criteria must be tailored to project objectives and the geophysical system(s) used.

(1) All "positioning seed items" (e.g. 8 to 10-inch nails) shall be detected and their locations interpreted within [specify distance] meter of their burial locations. Applicable to DGM. This test can be incorporated into QC and/or QA programs. The purpose of this test is to verify all operations related to data positioning are performed to meet project positioning needs. The distance specified is normally one-half the across-line line spacing objective, although smaller criteria values can be used if feasible and needed. For example, if a line spacing of 0.8m (2.5ft) is used, this criterion would be set to 0.4m. This test is implemented by placing small metallic items throughout a project site using high-accuracy surveying techniques. The goal is to use pieces of metal that will produce relatively large amplitude anomalies over small areas. Failure of the contractor to properly position the associated anomalies will normally require re-processing the data or re-collecting the data.

(2) All coverage seed items (e.g. 4 to 8-inch nails) shall be detected and removed. Applicable to analog mapping. This test can be incorporated into QC and/or QA programs. The purpose of this test is to verify analog mapping coverage. This test is implemented by placing small metallic items throughout a project site. Accuracy of placement will normally not be critical. The protocol for placing these seed items can be on a per operator basis or on a per team basis. The frequency for placing these items can be on a per parcel of land basis, per team per day basis, per operator per day basis, per lane basis, or other shorter or longer intervals of time. The goal is to use pieces of metal that will produce relatively large amplitude anomalies over small areas. Failure of the contractor to properly recover all coverage seed items will normally require re-mapping all affected parcels of land (if on a per team basis) or all affected lanes (if on a per operator basis).

(3) All inert MEC seeds and simulated MEC seeds shall be detected, their locations interpreted within [specify distance] meter of their burial points, and selected for placement on dig lists, or excavated during analog operations. Applicable to DGM and analog mapping. This test can be incorporated into QC and/or QA programs. The purpose of this test is to verify geophysical operations meet the project's MEC detection and anomaly resolution needs. The distance specified is normally one-half the across-line line spacing objective, although smaller criteria values can be used if feasible and needed. For example, if a line spacing of 0.8m (2.5ft)

is used, this criterion would be set to 0.4m. Note that most MEC are long and create large anomalies. Therefore, the objective should be to have any part of the buried item within the specified distance of the dig location; the specified distance need not be measured to the center of the item. This test is implemented by placing inert MEC or simulated MEC items throughout a project site using high-accuracy surveying techniques. Items must be placed at depths that test both the procedures and detection capabilities. To test procedures, seed items must be placed at depths that produce sufficient SNR such that the item can unambiguously be detected and resolved. To test detection capabilities, seed items must be placed at depths that test either the maximum contract-required detection depth or the maximum achievable detection depth, as determined by the PDT during project planning. Seeding rates will vary, but optimum rates would test each DGM dataset or each analog instrument operator daily. Failure of the contractor to properly detect, select and resolve the associated anomalies will require process-specific root cause analysis and corrective actions. For DGM operations corrective actions may include re-processing the data or re-collecting the data. For analog operations corrective actions may include re-mapping by the sweep team, or DGM mapping of affected areas.

(4) DGM maps shall represent as best as possible the actual potential field as it existed at the time of data collection. Applicable to DGM. Tests associated with this statement are normally incorporated into the QC program. This statement is intended to capture all typical field and processing steps needed to address known failure modes common to most geophysical systems. Tests include checking that all measurement positioning corrections (latency and sensor offset corrections) are implemented, diurnal corrections (for magnetics) are performed, repeatability tests are successful, sensor response tests (commonly referred to as the "spike" test) are within tolerance, personnel tests are successful, noise level tests are successful, drift corrections are properly applied, and cable tests are successful. Failure of any one test will normally result in either re-processing the data or re-collecting the data. The reader is referred to the *Ordnance and Explosives Digital Geophysical Mapping Guidance – Operational Procedures and Quality Control Manual* (USAESCH, 2003) and *Quality Assurance Made Easy: Working With Quantified, Site-Specific QC Metrics* (Proceedings of the UXO/Countermine Forum, 2004) for more details and examples of how these individual QC tests are designed and implemented.

(5) Discovery of undocumented data coverage gaps that exceed the maximum allowable data gap distance of [enter distance] meter(s,) or excessive data gaps between the [enter project line spacing objective] and the maximum allowable data gap distance. Applicable to DGM mapping. This test can be incorporated into QC and/or QA programs. The purpose of this test is to verify geophysical operations meet the project's survey coverage objectives. The distances specified are normally defined during project planning, or may be specified in the SOW/PWS. The project's "line spacing objective" is defined as the design line spacing, such as 0.8m (2.5ft). Since most geophysical systems do not collect data along perfect straight lines, some tolerance may be factored into the QC/QA test criteria. For example, if the line spacing objective is 0.8m (2.5ft), and a 1m diameter sensor is being used, infrequent deviations from

the 0.8m objective may be tolerated to a limit of 1.3m while maintaining high confidence all MEC will be detected (the 1.3m distance being the "maximum allowable data gap distance", which would normally be defined from GPO data). Such allowable gaps are usually reported as a sum of all the areas not covered by the objective line spacing. Limits on the amount of "gap space" (missed areas) are typically set between 0.1% and 0.3% of the total area surveyed. If the total area "missed" exceeds this limit, data are collected in the gap areas. This test is implemented by calculating survey coverage using automated computer routines such as Geosoft's UXProcess. Failure of the contractor to properly cover the site will require process-specific root cause analysis and corrective actions and will require mapping missed areas.

(6) Discovery of undocumented or unresolved non-conformance or non-compliance as defined in the accepted QC plan. Applicable to DGM and analog mapping. Tests associated with this statement are normally incorporated into the QA program. The purpose of this statement is to clearly assure that the Contractor shall be responsible for performing and documenting all tasks required in the QC program. This test is usually performed by reviewing some or all of the Contractor's QC documentation for thoroughness and completeness. Failure of the contractor to detect a failed QC test or failure of the contractor to have initiated a root-cause analysis after detecting a QC failure will normally result in the Government's rejecting all associated work products until all required QC tasks are complete. QC Pass/Fail criteria should be developed, as applicable, for each QC test specified in the QC Plan. Table 9-1 presents examples of common QC tests currently used.

(7) Verify all above-background anomalies are uniquely identified [optional: with the following anomaly characteristics calculated: centroid location, area of contiguous above-background measurements, peak responses and the SNR (calculated as signal power above estimated background power) based upon all above-background measurements]. Applicable to DGM. These tests can be incorporated into QC and/or QA programs. Tests associated with this statement will normally be devised to verify that instrument responses with above-background signatures are identified for further analysis and possible placement onto dig lists. Most tests will involve reviewing some or all geophysical data to confirm all above-background signatures meeting project specifications are tabulated in an anomaly table. Failure of the contractor to meet anomaly detection requirements will normally result in re-processing and/or re-interpreting the data.

(8) Verify all [MEC-like or Project-required] anomalies are selected and loaded into dig lists. Applicable to DGM mapping. These tests can be incorporated into QC and/or QA programs. Tests associated with this statement will normally be designed to check that anomalies selected on dig lists meet project needs. Most tests will involve reviewing some or all anomaly dig lists and associated geophysical data and/or maps to confirm those anomalies listed have anomaly characteristics meeting project specifications and to confirm those not listed do not have characteristics that meet project specifications. Tests may also include verifying appropriate anomaly selections to confirm automatic anomaly picking routines do not

adversely increase the number of anomalies listed on dig sheets, which is of particular concern on characterization projects where the number of contracted excavations is limited or projects where anomaly excavations are a time and materials task. Failure of the contractor to meet anomaly selection requirements will normally result in re-processing and/or re-interpreting the data.

(9) Discovery of a geophysical anomaly that was not detected through normal mapping/sweeping operations, and which has characteristics similar to, or greater than, those defined from target objectives buried at depths specified [by the PDT or in the PWS/SOW]. Applicable to DGM and analog mapping. Tests associated with this statement are normally incorporated into the QC and/or QA program. Tests will normally be based on finding anomalies during QC or QA inspection having characteristics associated with MEC buried at depths determined to be “detectable” (e.g. the probability of detection is high.) Initial project-specific anomaly characteristics can be defined from the GPO and may include signal-to-noise ratios (digital), spatial extent of above background measurements (analog and digital), fit-coefficients from modeling software (digital), peak amplitude responses (analog and digital), or any other quantifiable measure of anomaly characteristics specific to the instrumentation used. For QC or QA inspections that use DGM, these characteristics should not be limited to simple threshold characteristics of peak amplitude response. For QC or QA inspections using analog instruments, these characteristics will likely be limited to simple peak threshold responses (e.g. audio tone or needle deflection) and may include spatial extent of above-background measurements. Failure of the contractor to detect and resolve MEC-like anomalies that are easily detected will normally result in re-processing or re-interpreting the data or re-mapping the associated area(s).

g. Example quality standards for anomaly resolution procedures and how they are used.

(1) Typical quality Pass/Fail tests for anomaly resolution activities are listed below. Each is identified as applicable to digital mapping, analog mapping or both. A brief description of how each is implemented is also provided. When any specific test is used, it will normally be tailored to site-specific and contract-specific needs and requirements. Where applicable, Pass/Fail criteria should be defined using current knowledge of the project site(s). The Pass/Fail criteria would normally be revised in the event new information about a site is discovered over the course of the project. These tests will be designed around how the Contractor performs their anomaly resolution processes. Those processes should be capable of successfully excavating or otherwise positively resolving all anomalies tabulated on dig lists or anomalies identified during analog mapping. The purpose of the Contractor’s QC Plan for anomaly resolution should be to define what is meant by “resolved anomaly” and verify each anomaly is unambiguously resolved. The Contractor’s work plan or QC plan should include a detailed plan for managing anomalies reported as false positive, no contact, “hot-rock” or “geology”. If the examples below are used by the PDT, the example Pass/Fail criteria must be tailored to project objectives and the procedures used.

(2) Note: for most analog mapping projects, the Government's QA tasks can be simplified by requiring the Contractor to leave the lane markers in the grid until all field-level QA is complete. For all projects, the Government's QA tasks can be simplified by requiring the Contractor to flag all excavated locations and to leave all flags in the excavated location until field-level QA is complete. Where appropriate, the flags should be labeled with the unique anomaly identifier.

(a) Discovery of an unresolved anomaly listed on a dig list or at a location previously identified during analog mapping operations. The term unresolved is defined as 1) a geophysical signature of unknown source is still present at a location specified on a dig list or an excavated location after it has been declared complete and accepted through the project QC program, or 2) an anomaly is reported as no-contact, false positive, hot-rock or geology but does not meet the requirements for such under the management plan for reporting the false-positives, no-contact, hot-rock and geology. Applicable to DGM and analog procedures. Tests associated with this statement are normally incorporated into the QA program. Tests for case (1) will normally be based on QA inspections at locations tabulated on dig lists. Anomalies at such locations having characteristics associated with MEC buried at depths determined to be "easy" to detect (same as item (7) above), for which the source is not known, will result in failure. Tests for case (2) will normally involve reviewing some or all anomalies reported as false-positive, no-contact, hot-rock or geology for compliance with project-specific criteria. Failure of the contractor to unambiguously resolve anomalies will normally result in the Government's rejecting all associated work products until all associated root-cause-analyses are complete and all corrective actions have been performed.

(b) Discovery of undocumented or unresolved non-conformance or non-compliance as defined in the accepted QC plan. Applicable to DGM and analog mapping. Tests associated with this statement are normally incorporated into the QA program. The purpose of this statement is to clearly assert the Contractor shall be responsible for performing and documenting all tasks required in the QC program. This test is usually performed by reviewing some or all of the Contractor's QC documentation for thoroughness and completeness. Failure of the contractor to detect a failed QC test or failure of the contractor to have initiated a root-cause analysis after detecting a QC failure will normally result in the Government's rejecting all associated work products until all required QC tasks are complete. QC Pass/Fail criteria should be developed, as applicable, for each QC test specified in the QC Plan. Table 9-1 presents examples of common QC tests currently used.

(c) Verification of excavated anomaly locations using geophysical sensors to confirm anomalies are resolved. Applicable to DGM and analog mapping. This is similar to item (2) above. Tests associated with this statement are normally incorporated into the QC and/or QA program. Tests will normally be based on finding unresolved anomalies during QC or QA inspections using geophysical sensors. For this test, unresolved is defined as a geophysical sensor still detects an above background signal over an excavated location, and that signal has characteristics similar to those of MEC. Failure of the contractor to unambiguously resolve anomalies will normally result in the Government's rejecting all associated work products until all associated root-cause-analyses are complete and all corrective actions have been performed.

(d) Verify dig result findings are reviewed and approved by a qualified Geophysicist. Applicable to DGM and analog mapping. Tests associated with this statement are normally incorporated into the QC and/or QA program. Tests for this activity may be similar to those for item (1) above as these are related topics. Tests will normally focus on confirming the descriptions of items recovered during anomaly excavations adequately explain the anomaly characteristics observed in the geophysical data. Tests will also involve reviewing the reported excavation results for compliance with management plan for reporting findings of false positives, no contacts, hot rocks and geology. Tests may also include reviewing reported information for compliance with standardized reporting nomenclature. Failure of the contractor to verify reported dig findings will normally result in the Government's rejecting all associated work products until all associated root-cause-analyses are complete and all corrective actions have been performed.

9-3. Product Quality Management. The PDT must define what the project-specific final products will be and what results must be achieved for each. The PDT will then need to determine how best to assess the quality of those products. There are two types of products produced from geophysical surveys for MEC projects: tangible products, such as reports and work plans, and intangible products such as instrument interpretations and declarations that work in a parcel is "complete".

a. Common Tangible Geophysical Products and Related Standards. Listed below are common tangible products that can be included in the geophysical quality management programs:

(1) Complete work plans and quality control plans

(2) Complete GPO reports

(3) Complete geophysical investigation reports

(4) Fully completed dig sheets

(5) Properly formatted and documented geophysical data

(6) Legible and complete maps showing the geophysical survey's results and interpretations

(7) Fully supported anomaly selection criteria and decisions.

(8) Quality standards for the products listed above will normally include adherence to standard reporting formats (such as DIDs), completeness requirements, and may include requirements that documents be legible, concise, accurate and use proper grammar. For completed dig lists, acceptance sampling using guidance from MILSTD-1916 can be used for verification purposes. This may require returning to a prescribed number of anomaly locations to confirm those anomalies are indeed resolved. The reader is referred to MILSTD-1916 for detailed guidance on acceptance sampling. For most cases, a tangible product that does not meet a quality standard (as defined by the PDT and/or in the SOW/PWS) will not be accepted by the Government until all deficiencies have been corrected.

b. Common Intangible Geophysical Products and Related Standards. Listed below are intangible products from MEC projects that may be included in the geophysical quality management program:

(1) One or more parcels of land declared "clean" or declared as meeting project objectives, also referred to as "QC Complete, turned over to the Government for QA acceptance"

(2) Geophysical interpretations based on professional judgment, sometime also referred to as "manual" interpretations.

(3) Quality control and quality assurance of these products often takes the form of verification/acceptance sampling. In this context, verification/acceptance sampling is defined as any procedure used to validate a product after it has been turned over for government acceptance. Typical procedures currently include digitally mapping or re-mapping (to include re-sweeping for analog approaches) a portion of an area after it is declared free of MEC contamination. These current verification/acceptance sampling methods of intangible geophysical products are generally limited to re-mapping (or re-sweeping) sub-portions of a parcel of land; however, these approaches are not statistically meaningful unless large sub-portions (in the 85% to 95% range) of land are re-mapped. Further, the failure criteria must be the discovery of unresolved or undetected MEC-like geophysical anomalies. Re-mapping small sub-portions does not provide statistically significant information regarding the success or failure of an intangible analog or digital geophysics product. Failure criteria that do not factor for unresolved or undetected MEC-like anomalies provide little confidence in the product if such MEC-like anomalies are detected and do not result in root-cause analyses and corrective actions, as appropriate. If the PDT chooses to use re-mapping as a verification/acceptance sampling tool for quality control or quality assurance, they should do so only when process quality controls have a reasonable expectation of delivering uniform products and the PDT agrees on the definitions of *production units* and *lot sizes*. The terms *production units* and *lot sizes* are terms defined in MILSTD-1916, however, the reader is cautioned that statistically valid definitions for *production units* or *lot sizes* of intangible geophysical products are under discussion within the MRP community as of the date of this publication. The reader should

contact the MMRP CX for up-to-date information on this topic. It should further be emphasized that re-mapping of land parcels mapped using analog geophysical system should have failure criteria defined in terms of previously undiscovered or unidentified MEC-like geophysical anomalies, and not in terms of physical sizes of excavated objects. The reason this type of failure criteria is required is that the presence of such anomalies indicates either the analog geophysical mapping interpretations or coverage do not meet project objectives, or that instruments malfunctioned. If unexplained MEC-like anomalies are detected, a product failure exists. For properly designed QC plans of analog systems, a mechanism will be needed within the work plan for either removing all recovered MEC-like anomaly sources from the project site or otherwise identify them as previously discovered. This can be achieved by leaving pin flags at each such location, painting each item recovered, or specifying that any item discovered shall be left on the ground surface. This latter approach would prove difficult to implement if the density of such items is high and may mask sub-surface MEC still present, or if digital mapping techniques are used for QC or QA and the density of surface metal is high.

9-4. Managing Quality Control Failures.

a. This sub-section introduces the topic of managing QC failures and presents ideas of how to establish the meaning of QC failures. Because no geophysical system can guarantee all MEC are detected under all conditions, specific understandings of what a given QC failure indicates should be agreed upon up-front by the PDT. Not all QC failures indicate a breakdown in field processes or that defective or non-conforming products will result, sometimes they simply indicate local site conditions are less amenable to detecting MEC than others. In all instances, the quality control personnel should perform a root-cause analysis and determine to what degree the QC failure affects project decisions. QC failures that do not affect project decisions are less significant than those that directly impact project decisions. This sub-section provides some examples of how some QC criteria can be managed under different conditions. The list below is not all inclusive. The PDT should review each quality control test included in the quality control plan and outline a plan for managing failures in the event they occur. It may be beneficial to identify those types of failures that are minor in nature, those that are critical in nature, and those that could be either minor or critical depending on how it will affect project decisions.

(1) **Undocumented Survey Coverage Gap Too Large:** For many characterizations, the important factor is acreage investigated. If some datasets have gaps larger than that acceptable to the PDT, simply surveying an extra grid or transect may suffice, rather than needing to re-occupy small gaps in multiple grids or transects, which can be costly and time consuming. For response actions, the gaps need to be properly surveyed. Root cause analyses will normally focus on the source of the gap to determine if it is due to instrumentation (which is often visible in the track-plot maps), due to a breakdown in following field procedures (the track-plots are accurate, the data was simply collected along the wrong lines), or due to undocumented

obstacles. Gaps due to documented obstacles, such as trees or fences, should be addressed during project planning.

(2) **Along-track data density does not meet a project objective or metric:** In circumstances where no anomalies are detected in the affected area, the project needs may not warrant spending the time to correct this failure as it will not impact PDT decisions. If anomalies are present on the affected portions, these types of failures would likely not be allowed and appropriate actions required. Root cause analyses will be similar to those described in item (1) above.

(3) **Contractor fails to detect a seeded anomaly:** Some seed items may go undetected if they are buried at depths difficult for the geophysical system to detect. If all other data quality tests and system checks indicate the data is of high quality, it may not be possible to reliably detect that seed item under the conditions it is buried in. In this circumstance, the PDT should be notified of the failure as it may affect the project's detection capability objectives or PDT expectations. Root cause analyses will normally focus on reviewing the geophysical and related QC data, reviewing the anomaly detection and selection criteria. They may include re-collecting data over the location to confirm it indeed can not be detected.

(4) **Calculated background noise levels for a dataset exceed a QC threshold:** It is common for background noise levels to change over a project site. Normally, this metric is used as an indicator that instrument platform integrity is degrading, or that instrument failure may be occurring. The root-cause analyses will normally focus on reviewing the affected dataset(s) and associated areas for abnormal measurement spikes (indicative of degrading instrument platform integrity or instrument failure), local terrain conditions, local geology conditions, or an increase in "clutter" due to proximity to a target area. If local terrain, geology or clutter is suspected, the analyses will normally include re-collecting small amounts of data in one or more affected datasets to prove the increased noise levels are repeatable. If the increased noise levels are reproduced, adjusting the threshold upward for such areas may be warranted. If they are not, then either problems with the integrity of the instrument platform is the cause or instrument failures occurred.

(5) **Anomaly reacquisition team reports a false positive for a large amplitude anomaly, or anomaly resolution team reports a small piece of metal for a large amplitude anomaly:** For site characterizations, a small number of such failures may be acceptable, particularly if returning to the anomaly location for more thorough excavations would not affect project decisions. Such a scenario would exist if the anomaly is located in an area already confirmed as being contaminated with MEC, or if large numbers of surrounding anomalies are reported as unrelated to DoD activities and there is reasonable statistical justification that the missed anomaly is not MEC or MEC-related. In these circumstances, even though the failure indicates a possible significant process failure, or possibly a significant instrument failure, returning to the actual anomaly would not affect decisions for that area. For response actions

these types of failures would likely not be allowed and appropriate actions would be required for each such anomaly. Root cause analyses will normally focus on the procedures the contractor uses to document excavation results and how that information is provided, reviewed and accepted by geophysical and QC personnel.

(6) **QC mapping (using either digital or analog systems) of an analog geophysics lane detects an undocumented or previously undiscovered MEC-like geophysical signal.** Since analog systems benefit only from being able to discriminate very small and shallow anomaly sources from very large and deep sources, most signals must be excavated in order to determine if the source is MEC or not. If during a QC re-sweep a signal is detected that must be excavated to determine if it is MEC or not, the finding indicates a significant failure in how the analog geophysical system detected MEC. For characterization surveys, this finding may not be significant for the same reasons explained in example (5) above. Similarly, for response actions, this finding would likely constitute a significant failure requiring appropriate actions be taken. Root cause analyses will focus on why the operator’s interpretation of his or her geophysical instrument was in error, why their coverage of their lanes does not meet project objectives, or if their geophysical sensor failed. Typically, the analyses will include reviewing field logs for discrepancies, interviewing the responsible team leader, and re-sweeping additional portions of the affected area, or additional lanes mapped by the responsible individual(s).

(7) **A QC Function Check exceeds a QC threshold.** Most QC function checks are designed to demonstrate whether the instruments are functioning properly or not. If all reviews of the associated data and all other function checks indicate proper instrument functionality, then the QC failure is not likely to affect project decisions. The root cause analyses will normally include reviewing all associated data for indications of instrument failure, reviewing all other QC function check results for evidence of instrument failure, and review of how the field team implements the QC function check procedures. The analyses may also include re-collecting data over small portions of associated areas to prove whether or not instrument failure occurred.

9-5. <u>Special Considerations for Quality Control Programs</u>.

a. MEC Characteristics and Burial Characteristics That Affect QC

(1) The characteristics of the target MEC and how it could be buried must be factored into the quality control plan. For example, most MEC have shapes that are axially symmetric, similar to tear drops (mortars and bombs), elongated egg-like shapes (MK2 grenades) circular or dumbbell shaped (rockets) or bullet shaped (large caliber projectiles). These types of items produce responses with very different SNR in most detectors when they are buried at different angles but at the same depths. For instance, most commonly used horizontal-loop TDEMI detectors can detect most projectiles at much greater depths when buried in a vertical

orientation as opposed to a horizontal orientation. What this means is that a MEC item that may go undetected at one depth when buried in one orientation will produce a high SNR and be easily detected if buried in another orientation at the same depth. For this reason, QC inspections should not focus only on the physical size of items recovered, but rather should focus on the instrument measurements recorded or observed during the QC inspections.

(2) The QCP must differentiate between detection capabilities and task results. The term task results refers to results from all field activities associated with the detection and removal of MEC, and includes geophysical mapping, anomaly reacquisition and anomaly resolution. The QCP must therefore factor for the limitations of the geophysical system to effectively detect all MEC as stated in the project objectives. Essentially, the QCP must differentiate quality elements that define what is meant by “good data” from quality elements that are affected by technology limitations. As an example, the QCP may need to differentiate MEC anomaly characteristics that must always be detected from MEC anomaly characteristics that may sometimes go undetected or unselected. For the former (good data), quality control measures are developed to verify all such signatures are detected and selected. Finding such a signature during QC inspections would strongly suggest a major defect in work task products. For the latter (technology limitations), QC measures will focus on how project decisions are made, and finding such signatures during QC inspections may or may not suggest defects in work task products. As an example, if a weak anomaly is detected that may be MEC or may be geologic noise turns out to be MEC, then finding such a signature during QC inspection either suggests a product defect or a limitation of the technology. It would be deemed a product defect if, during the root-cause analysis, it is found the quality of the underlying geophysical data does not meet project needs (such as having too many data gaps, or the sensor noise levels are too high and could have been reduced). If, on the other hand, the quality of the data is good, then finding a MEC suggests not all project objectives can be achieved using current technologies because the probability of detecting that MEC under those site-specific conditions is less than 1. Another possibility in this scenario is that the project decision criteria are not sufficiently stringent to meet all project objectives (i.e. the anomaly selection criteria were set too high) and more anomalies with lower signals must now be selected using adjusted criteria. Whatever the cause of quality failures, whether related to data quality or technology limitations, root-cause-analyses will be system-specific, and should be thorough. The Government geophysicist should verify that all possible causes of the failure have been identified and, if appropriate, each is tested to confirm or refute each possibility. As an example, one common QC test used to monitor sensor performance is to quantify the variations in background measurements by calculating their standard deviation. This metric is used as one of several means to monitor for instrument malfunction, and QC pass/fail criteria will typically be established using GPO data at a time when the sensor was proven to be functioning properly. However, as site conditions vary, often as the areas surveyed approach a target zone or the underlying geology changes, the calculated background variations will increase to the point where the noise pass/fail test fails. The root cause analysis will likely include testing system cables for shorts, testing sensors for

broken components or bad connections, and if no obvious sources are found and geology or site conditions are suspected, the sensor will likely be re-deployed over the area to confirm the increased noise levels are reproduced. If confirmed as such, the corrective actions will normally be limited to adjusting anomaly selection criteria to factor for increased noise levels in affected areas.

b. MEC Detection Variabilities That Affect QC

(1) The types of issues presented above in MEC Burial Characteristics stem from the fact that most detectors can not reliably discriminate MEC from non-MEC and non-MEC items can produce very large geophysical signatures, though their physical size may be smaller than project target objectives. Since such non-MEC geophysical signatures can not be differentiated from MEC signatures, all such signatures must be investigated. More importantly, these are the types of anomalies that should not be present in any post-removal quality control or quality assurance inspection, or post-removal verification data.

(2) For each type of MEC, the project team should define anomaly characteristics that must always be detected. Many MEC are sufficiently large that, under certain burial conditions, will always produce anomalies with unambiguous characteristics. Here the term unambiguous will normally be associated with high SNR, high peak amplitude, and/or large spatial area of above-background measurements. Other clearly definable, instrument-specific characteristics can also be used. Anomalies having signatures with these characteristics represent buried target items that may or may not be MEC. MEC associated with such anomalies will almost always be buried at depths shallower than the maximum detection depth the geophysical system is capable of detecting. The PDT must decide which anomaly characteristics will constitute a "process" failure if they go undetected or unresolved, and must also agree that anomalies with other characteristics may be present in QC, QA or post-verification data, even if those other characteristics can sometimes be associated with MEC. These latter characteristics will usually be associated with MEC that are buried at depths or orientations that are difficult to detect with certainty, and are commonly referred to as "difficult to detect anomalies" or "anomalies near the limit of detection" for a given geophysical system.